THE CHOICE OF KEY PARAMETERS OF EMC①

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ABSTRACT Based on lots of EMC technical tests, the key technical parameters, i.e. pouring temperature, height of liquid metal column, intensity and distribution of cooling water as well as casting speed are investigated. The main results obtained are as follows: 1) The appropriate pouring temperature is 710～740 ℃; 2) The optimum height of liquid metal column is 30～45mm; 3) The cooling water distribution determined by tests is reasonable and 4) The controlling principle of EMC process is to maintain the height of liquid metal column constant.
Key words electro-magnetic casting height of liquid metal column casting speed

1 INTRODUCTION

Electro-Magnetic Casting (EMC) is a kind of continuous casting technology without mould based on the principle of electromagnetic induction as shown in Fig. 1[1]. The characteristic of EMC is that liquid metal column is formed by electromagnetic force, and solidified by cooling water directly under moving. Because EMC ingot don't come to contact with mould, so its surface is very smooth and its inner structure has the advantages of well-distributed and meticulous and EMC ingot has higher mechnical properties than DC, especially rolling property[2]. However, the EMC process is affected by electromagnetic field, fluid field, temperature field, stress field and solute field simultaneously, EMC technical parameters are various and it's very difficult to adjust and optimize them. Moreover, these parameters affect the structure and mechnical properties of EMC ingot directly also. For this reason, the study of technical parameters is necessary.

Based on a lot of EMC technical tests, the key parameters, i. e. pouring temperature, height of liquid metal column, strength and distribution of cooling water as well as casting speed are determined.

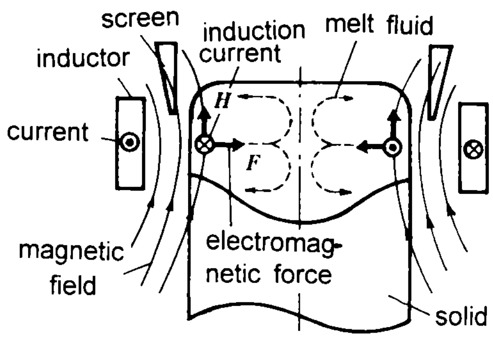

Fig. 1 **Schematic diagram of EMC**

2 TECHNICAL PROCESS OF EMC

The middle test device of EMC is shown in Fig. 2. It is composed of melting system, pouring system, cooling water box, pulling machine and controlling system as well as intermediate frequency power supply. Electromagnetic inductor is made from good conductivity copper plate. Stainless steel screen is used for reducing the affection of electromagnetic stirring and restraining surface flow of liquid metal and maintaining the balance between liquid metal static pressure and electro-

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magnetic force. The section of EMC pure aluminum ingot is 520 mm × 130 mm.

The technical process of EMC is as follows: melting→regulating the level and relative position among mould, inductor and screen → switching on the intermediate frequency power→pouring→cooling→pulling ingot down. The maximum power of intermediate frequency motor is 100 kW, its frequency is 2500 Hz; the current through the inductor is 3 000～6 000 A; the pulling machine is controlled by computer. Casting speed can be regulated from 0 to 25 cm/min freely.

3 CHOICE OF TECHNICAL PARAMETERS

Although the EMC process is affected by electromagnetic field, temperature field and fluid field etc. simultaneously, adjusting and controlling them is very difficult. However, research results show that the key technical parameters affecting EMC process are pouring temperature, height of liquid metal column, intensity and distribution of cooling water as well as casting speed.

3.1 *Pouring Temperature*

Fig. 3 shows the result pouring at 760 ℃. Since the heat in the ingot is conducted only through the bottom mould during the initial stage of EMC, liquid metal solidifies too slowly to form appropriate solid/liquid interface, the height of liquid metal column raises gradually when pouring temperature is high. Moreover, the surface tension maintaining shape of liquid metal column reduces, as soon as the hydrostatic pressure surpasses the electromagnetic force, the collapse drawback will take place on all sides.

Fig. 2 Device of EMC

The result pouring at 690 ℃ is shown in Fig. 4. Bad fluidity of liquid metal and rapidly solidifying constrict make it difficult to distribute equally liquid metal and to keep good meniscus, results in the ingot turning into tower shape and EMC process comes to failure at last.

EMC tests result shows that appropriate pouring temperature is 710～740 ℃ for pure aluminum.

3.2 *Height of Liquid Metal Column*

Fig. 3 Situation of high pouring temperature

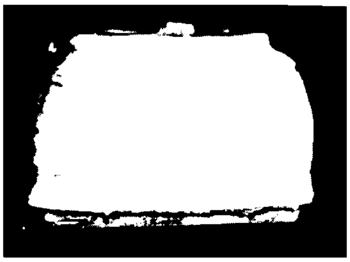

Fig. 4 Situation of low pouring temperature

EMC process has severe requirement for the liquid metal column: 1) Suitable height; 2) Vertical sides; 3) Stable surface. Any fluctuation of liquid metal column height not only changes ingot size, but also makes its surface rough, even leads to failure of the casting process[3].

The equilibrium relation among liquid metal hydrostatic force and electromagnetic force as well as surface tension pressure during EMC process is as follows:

$$\rho gh = P_m + P_s$$

where ρ is liquid metal density, g is acceleration of gravity, h is the height of liquid metal column, P_m is electromagnetic force, P_s is the surface tension pressure. Generally P_s is so small that it can be neglected. Obviously, the undulation of height of liquid metal column easily disturbs equilibrium relation.

Actually, Fig. 3 and Fig. 4 show the affection of liquid metal column height on EMC process as well. Fig. 5 indicates the local collapse owing to high liquid metal column.

Fig. 5 Local collapse owing to high liquid metal column

The spherical corner defect of EMC ingot will emerge when the height of liquid metal column is too low as shown in Fig. 6. The position of spraying water of one side about 5 mm higher than the other side of cooling water box makes liquid metal column of this side become low.

Fig. 6 Spherical defect owing to low liquid metal column

The results indicate that the corner of EMC ingot will become spherical when $h < 25$ mm and collapse drawback will occur when $h > 55$ mm, the optimum range of liquid metal column height is $h = 30 \sim 45$ mm.

3.3 *Distribution of Cooling Water*

For the EMC slab whose ratio of width to thickness is n, the heat in ingot will be conducted out from shortest distance under the condition of the same surface temperature according to the minimum resistant law, the heat distribution is shown in Fig. 7[4]. The thick lines show two-dimensional heat conduction zone, its areas is $S_2 = 4x^2$, the thin lines are one-dimensional zone, $S_1 = 4(n-1)x^2$. EMC process requires the S/L interface along ingot side to be at the same level. For this reason, the crystallizing coefficient of one-dimensional zone is twice that of two-dimensional zone. In order to determine reasonable distribution of cooling water, four kinds of cooling water distributions are proposed and casting tests are carried on. The obtained result is shown in Fig. 8. It can be seen that a good ingot section shape is obtained at position 1. As a result, a satisfactory cooling water intensity distribution is determined as shown in Fig. 9. Its reasonability is proved by temperature field analysis and measurement of S/L interface, i. e. the solidification time and the height of liquid metal column along ingot's all sides are identical[5].

3.4 *Casting Speed*

The casting speed - time curve is a compre -

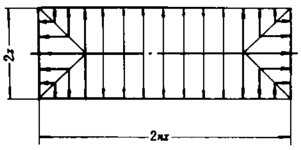

Fig. 7 Schematic diagram of heat conduction of slab

Fig. 8 Ingot with various cooling water densities

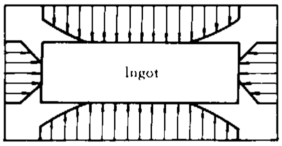

Fig. 9 Reasonable cooling water distribution

hensive reflection of EMC technical parameters matching, especially, there exists an intimate relation among pouring temperature, cooling intensity and casting speed. Moreover, the link connecting them is the height of liquid metal column. The controlling principle of EMC technical parameters is to maintain constant liquid metal column height during casting.

Fig. 10 shows the casting speed curve under the different casting conditions. The technical parameters used is shown in Table 1. It can be seen that the casting speed curve is divided into three parts clearly: 1) Initial stage,

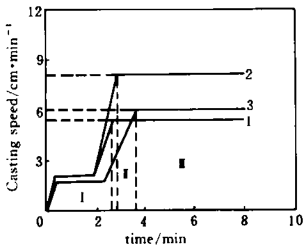

Fig. 10 Velocities versus time

2) Transition stage and 3) Stable stage. During the initial stage 1, the solidification rate is very small since the heat in ingot is conducted out by bottom mould only, so a relatively low casting speed is used to maintain the liquid metal column height constant. During the transition period, owing to the cooling water spraying upon the ingot directly, the solidification rate increases suddenly, therefore, casting speed increases quickly. When a new heat equilibrium is reached, that is to say, the height of liquid metal column becomes constant, EMC process enters into the stable stage. In stage 3, cooling water intensity, solidification rate, casting speed and height of liquid metal column don't change with time, velocity versus time curve is a straight line.

Table 1 Technical parameters of EMC

curves	T_p /℃	Q_w /$m^3 \cdot h^{-1}$	h /mm	V_z /$cm \cdot min^{-1}$
1	720	2.0	38～40	5.6
2	720	3.5	38～40	8.0
3	730	3.0	38～40	6.0

The results in Fig. 10 indicate that when pouring temperature $T_p = 720$ ℃, if cooling water flow Q_w changes from 2.0 to 3.5 m^3/h, the casting speed V_z increases correspondingly from 5.6 to 8 cm/min to maintain the liquid metal column height $h = 38 \sim 40$ mm (curve 1 and 2).

When pouring temperature T_p increases from 720 to 730 ℃, keeping casting speed without change, the cooling water intensity Q_w must increase from 2.0 to 3.0 m³/h. Moreover, the casting speed in the initial stage reduces and transition time is elongated also when increasing pouring temperature (curve 1 to 3). Fig. 11 shows the EMC pure aluminum ingots basing on those technical parameters in Table 1, ingot's section is 520 mm × 130 mm.

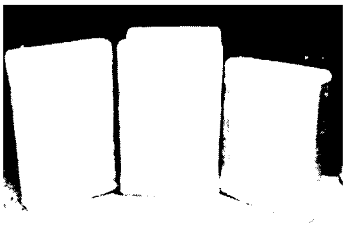

Fig. 11 Pure aluminum ingots of EMC

4 CONCLUSIONS

(1) The appropriate pouring temperature is T_p = 710~740 ℃ for pure aluminum.

(2) The optimum liquid metal column height is h = 30~45 mm.

(3) The cooling water intensity distribution determined by tests is reasonable.

(4) The controlling principle of EMC process is to maintain the liquid metal column height constant.

REFERENCES

1 Getselev Z N. J of Metals, 1971, 23(10): 38.
2 Masahiro Yoshida. ISIJ, 1987, (3): 403.
3 Zhu Xiaoying. Doctor dissertation of Dalian University of Technology, 1990.
4 Zhang Shaoxiang. Processing Technology of Light Alloys, 1985, (10): 1.
5 Zhang Xingguo, Cao Zhiqiang, Jin Junze. Hot Working Technology, 1994, (2): 3.